28 p

COMPUTER CODES FOR THE EVALUATION OF SPACE RADIATION HAZARDS

VOL. 6. ELECTRON TRANSMISSION

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GENERAL INFORMATION

PURPOSE

29368

The purpose of this program is to compute the space radiation dose caused by electrons being transmitted through a radiation shield.

Required inputs for the program are:

1. Electron flux to dose conversion table
2. Energy spectrum being used
3. Atomic number of shield material
4. Layer thickness for each solid angle for each sector

The program is presently set up to handle only one type of material at a time. Dose may be calculated at any point inside a vehicle.

Author

ASSUMPTIONS

In the cases of three-dimensional shields (such as space vehicles), the shield is assumed to be approximately spherical.

LIMITATIONS

The mathematical formula for transmission of electrons is derived from the electron Monte Carlo data (Ref. 1).

The analysis is for one material only, and a shield of more than one kind of material must be treated as though every layer consists of the same material.

RECOMMENDATIONS

It is recommended that this program be expanded to analyze radiation shields composed of more than one type of material.

PROCEDURE

NOMENCLATURE

The nomenclature is presented in Table 1.

METHOD

From an empirical study, it is found that electrons from radiation belts encircling the earth will produce a radiation dose (D_i) equal to:

$$D_i = \Omega \int_{E_o}^{E} \left[T(E)\,\phi(E)\,\frac{dE}{dx}(E) \right] dE$$

where the following is true:

1. T(E) is the transmission of one electron through a shield of thickness X and atomic number Z. It is found empirically to fit the curve

$$T(E) = \exp\left\{ - \left\{ \left[\left(\frac{0.585 Z^{-0.271}}{X} \right)^{0.848} (E) \right]^{-7(Z-3.25)^{-0.24}} \right\} \right\}$$

This value of T(E) is computed in subroutine FUNCT(E, N) with E = electron energy in Mev.

2. ϕ (E) is the energy spectrum from a particular radiation belt. Values for ϕ(E) for each of three spectra are calculated in subroutine ELSI (EE, N) where EE is the electron energy and N is 1, 2, or 3 depending on the spectrum being considered.

3. $\frac{dE}{dx}$(E) is the ionization loss for an electron of energy E (Mev) of

TABLE 1. Nomenclature

MATH SYMBOL	PROGRAM SYMBOL	DEFINITION	UNITS
	ET	Entry (Energy) in table	Mev
	DIVX	Entry $(\frac{dE}{dx})$ in table	Mev-cm^2/gm
	D	Dose through one thickness of a given material	Mev/cc
D	DOSE	Summation of all D's	rads
X_i	X(I)	A particular thickness	gm/cm^2
Ω_i	O(I)	A particular solid angle	steradians/4π
Z	Z	Atomic weight of particular material	Pure No.
	NP	Number of problems or number of different types of shield materials	Pure No.
	NA	Number of entires in ET-DIVX table	Pure No.
E_o	XL	Lower limit of integration	Mev
E	XU	Upper limit of integration	Mev
	RO	Dummy density (=1)	gm/cc
	NE	Energy spectrum being used (NE = 1 for Carter Artificial NE = 2 for Mar Artificial NE = 3 for Van Allen Belt)	Pure No.
	NX	Number of sectors of shielding	Pure No.
	SOURCE	Number of incident electrons	Electrons/cm^2
	FACT	Fraction of incident electrons entering shield	Pure No.
ϕ (E)		Symbol for a particular energy spectrum	Mev^{-1}

the material for which the dose is calculated. Values for $\frac{dE}{dx}$ (E) are taken from Ref. 2. This is done by subroutine DEDX, using linear interpolation.

For each thickness X, the product of T(E), ϕ (E), and $\frac{dE}{dx}$ (E) is integrated over the range of possible values of E to obtain the dose. If the dose is desired through a particular solid angle of shield, say Ω, then the integral is multiplied by Ω.

The total dose through the shield is, then, taken to be the sum of the individual doses through particular thicknesses and at various solid angles.

RESULTS

Because of the complexity of the integration involved, only one hand calculation was made. The same case was run on the machine, and the two results were found to differ by 6%.

Also, the values for $\frac{dE}{dx}$ (E) were taken from an U. S. Bureau of Standards publication (Ref. 2). The expressions for ϕ (E) were the natural and artificial trapped electron spectra (Refs. 3 and 4).

It was, therefore, decided that the values this program was generating for T(E) would establish the validity of the program. These values were consequently compared with values for the transmission computed in a previously written program (Ref. 1), and were found to be in agreement with them.

INPUT PREPARATION AND OUTPUT DESCRIPTION

INPUT DATA

Input data for this program may be divided into five (5) groups as follows:

Group I. This group consists of two cards. The first card contains two integers, NP and NA, in a 2I 5 format. NP is the number of problems to be run, and NA is the number of entries in the ET - $\frac{dE}{dx}$ table for tissue. The second card contains three floating point variables, XL, XU, RO, in that order, and with a format of 3 F 10.0. XL and XU are the lower and upper limits of integration, and RO is the density (=1 for rads). In the case of the artificial electron belt, the upper limit XU is about 10 Mev. Since electrons having energy lower than 0.1 Mev are not very penetrating, XL = .1.

Group II. The second group of cards contains the entries for the ET - $\frac{dE}{dx}$ table for tissue. Each contains eight (8) floating point numbers in an 8 F 10.0 format. The first number on a card is ET, the second is the corresponding $\frac{dE}{dx}$, the third ET, etc. There will be approximately $\frac{NA}{4}$ such cards.

Group III. This card contains HOLLERITH information to be printed out at the end of the run.

Group IV. This group consists of the following cards:
NX which is right adjusted in columns 1-6, NE, which is right adjusted in columns 13-18, SOURCE in columns 37-48 with an E12.0 format, FACT in columns 49-54 with a F6.0 format, and Z in columns 55-60 with a F6.0 format.

NX is equal to the numbers of sectors in a vehicle.

NE is the index for the energy spectrum.

SOURCE is the incident electron flux in particles per square centimeter.

FACT is the fraction of the incident flux entering the shielding.

Z is the atomic number to be used for all shield layers.

Group V. The first card contains N according to an I6 format in columns 1-6, and 0 according to an E12.0 format in columns 7-18. N is equal to the number of material layers in the sector, and 0 is the weight associated with the sector.

There follow N cards which each contain a value of XT according to an E12.0 format in columns 7-18. The set of XT's are the thicknesses of each of the material layers in a sector.

These card formats were used in order that the same data cards might be used for all the space radiation shielding programs.

The input data may also be divided into two general groups: those variables which normally will not be changed, and those variables which must be changed to obtain different runs.

The first of these groups consists of the variables NA, XL, XU, RO, ET - $\frac{dE}{dx}$ table, SOURCE, and FACT.

Those variables which may change from one run to another are: NP, NE, NX, Z, X-values, and Ω-values.

OUTPUT DATA

The output data appear on a listing with appropriate headings and titles and is self-explanatory.

PROGRAMMING INFORMATION

This program is designed to correspond to the IBM 7090/94 FORTRAN monitor system. Input data are read from logical tape 5 by the FORTRAN READ INPUT TAPE statement. Output to be printed is written on logical tape 6 using the FORTRAN WRITE OUTPUT TAPE statement. No special tapes are required. There are no console switch settings required. Termination of the run is caused by a call to EXIT (returns control to the monitor) when the specified number of cases has been processed.

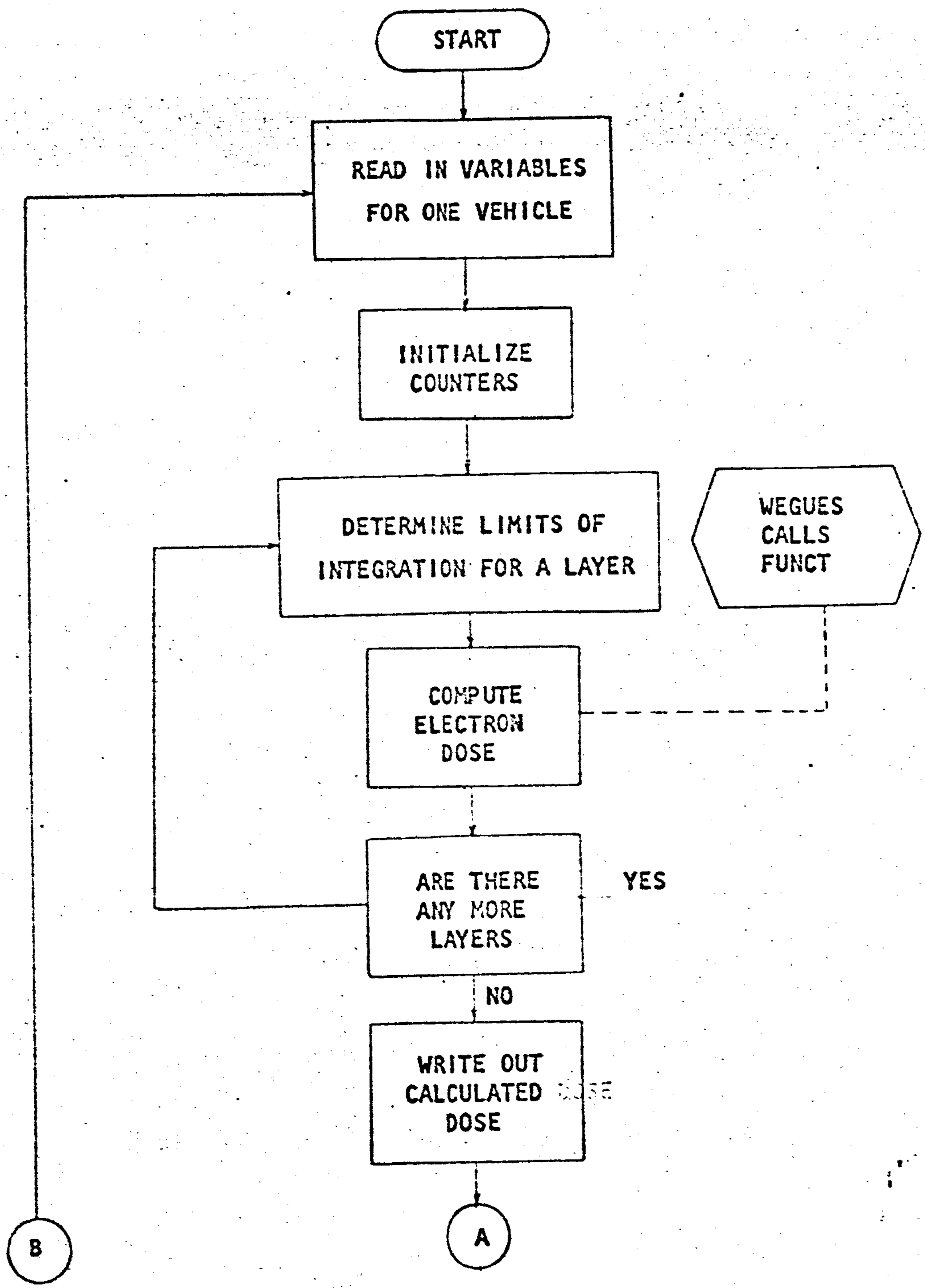
The program, excluding routines provided from the standard library, requires approximately 2,400 storage cells. Of this amount, 2,000 locations are required for storage of machine instructions and non-COMMON data, and 400 cells for COMMON data storage.

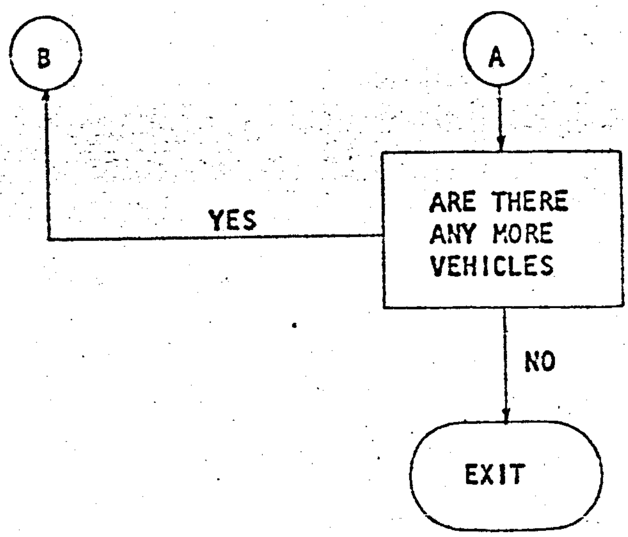
Routines taken from the library are:

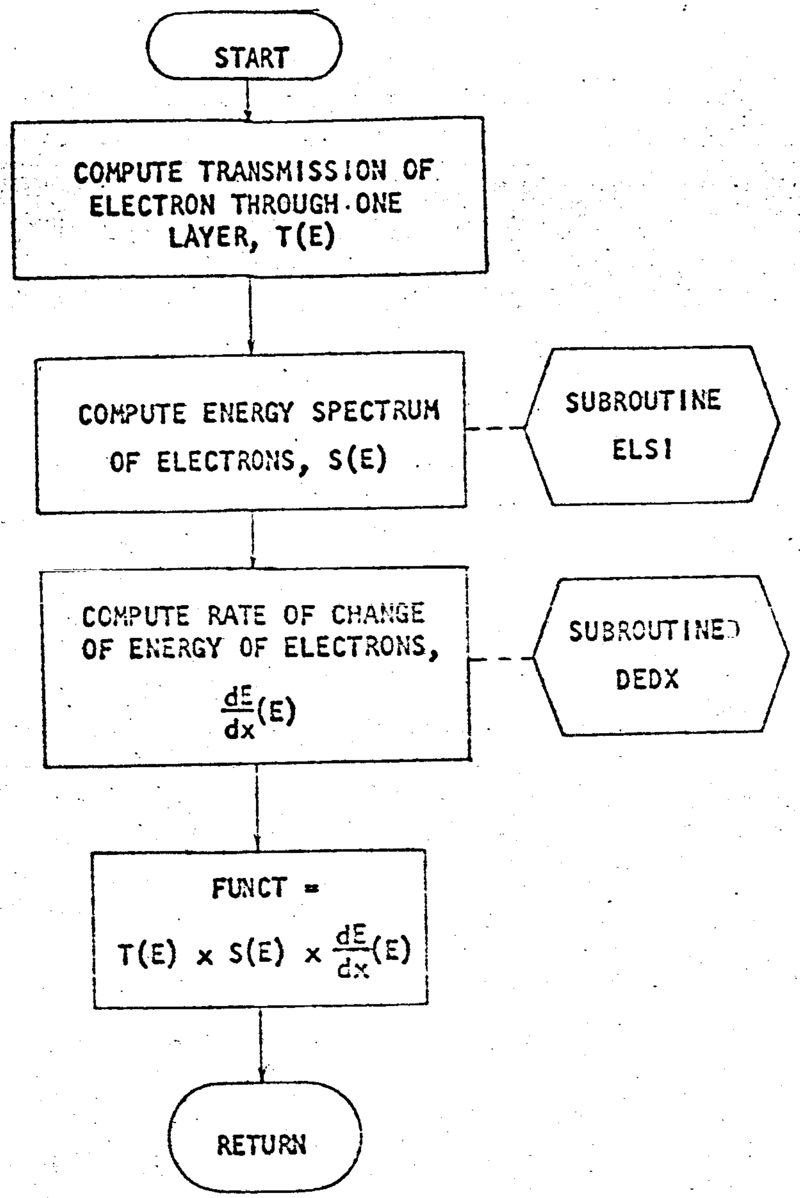
EXP	exp(X)
EXP(3)	Called by X**Y
EXIT	Returns control to monitor system

In addition, those routines required by the FORTRAN system for input and output are used.

FLOW CHARTS


START
READ IN VARIABLES FOR ONE VEHICLE
INITIALIZE COUNTERS
DETERMINE LIMITS OF INTEGRATION FOR A LAYER
WEGUES CALLS FUNCT
COMPUTE ELECTRON DOSE
ARE THERE ANY MORE LAYERS
YES
NO
WRITE OUT CALCULATED DOSE
A
B


B
A
ARE THERE ANY MORE VEHICLES
YES
NO
EXIT



Flow Chart of Subroutine FUNCT

PROGRAM LISTING

```
      DIMENSION ET(200),DIVX(200),D(350),X(350),O(350),PROB(12)
      DIMENSION XT(12)
      COMMON ET,DIVX,X1,Z,NA
    5 READ INPUT TAPE 5,10,NP,NA,XL,XU,RO
   10 FORMAT(2I5/3F10.0)
      READ INPUT TAPE 5,11,(ET(I),DIVX(I),I=1,NA)
   11 FORMAT(8F10.0)
      DO 40 J=1,NP
    9 READ INPUT TAPE 5,14,PROB
   14 FORMAT(12A6)
      READ INPUT TAPE 5,12,NX,NE,SOURCE,FACT,Z
   12 FORMAT(I6,6X,I6,18X,E12.0,2F6.0)
  152 FORMAT(I6,E12.0)
  153 FORMAT(6X,E12.0)
      ERR=0.01
      DOSE=0.0
      DO 30 I=1,NX
      READ INPUT TAPE 5,152,N,O(I)
      READ INPUT TAPE 5,153,(XT(J),J=1,N)
      X(I)=0.0
      DO 151 J=1,N
  151 X(I)=X(I)+XT(J)
      X1=X(I)
      B=-7.*((Z-3.25)**(-.24))
      A=.585*Z**(-0.271)
      E1=10.**(1./B)*(X1/A)**.848
      EL=MAX1F(E1,XL)
      IF(EL-XU)21,21,20
   20 D(I)=0.
      GO TO 30
   21 CALL WEGUES(EL,XU,NE,D(I),ERR)
C     CONVERTING MEV/CC TO RADS
      D(I)=D(I)*1.6E-8/RO*SOURCE*FACT
   30 DOSE=DOSE+D(I)*O(I)
      SUM1=0.
      DO 3942 JK=1,NX
 3942 SUM1=SUM1+O(JK)
      TERM=DOSE/SUM1
      DOSE=TERM
      WRITE OUTPUT TAPE 6,31,J
   31 FORMAT(1H1,51X,14HPROBLEM NUMBERI3)
      WRITE OUTPUT TAPE 6,32,PROB
   32 FORMAT(/12A6)
      WRITE OUTPUT TAPE 6,33,SOURCE,FACT,NE,Z
   33 FORMAT(/16H ELECTRON FLUX =F10.3,12H/CM**2/SEC, 43HFRACTION OF INC
     1IDENT FLUX ENTERING SHIELD =F10.3/18H SPECTRUM NUMBER =I3,2H, 34HA
     2TOMIC NUMBER OF SHIELD MATERIAL =F10.3)
      WRITE OUTPUT TAPE 6,34,(D(I),X(I),O(I),I=1,NX)
   34 FORMAT(//26X,4HDOSE25X,9HTHICKNESS,21X,11HSOLID ANGLE/26X10H(RADS/
     1SEC)19X10H(GM/CM**2)//(E28.5,2F32.5))
      WRITE OUTPUT TAPE 6,36,DOSE
   36 FORMAT(1H0,12HTOTAL DOSE =E15.7,12HRADS PER SEC)
   40 CONTINUE
```

```
GO TO 9
END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
FUNCTION FUNCT(E,N)

FUNCTION FUNCT(E,N)
DIMENSION ET(200),DIVX(200)
COMMON ET,DIVX,X1,Z
P1=-7.*((Z-3.25)**(-0.24))
B1 = (.585*(Z**(-0.271)))/X1
P2 = B1**0.848
B2 = (P2*F)**P1
TE = EXPF(-B2)
SE=ELSI(E,N)
DE=DEDX(E)
FUNCT=TE*SE*DE
RETURN
END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      FUNCTION DEDX(E)
      DIMENSION ET(200),DIVX(200)
      COMMON ET,DIVX,X1,Z,NA
      J=2
    1 IF(E-ET(J))5,6,7
    5 DEDX = DIVX(J)-((ET(J)-E)/(ET(J)-ET(J-1))*(DIVX(J)-DIVX(J-1)))
      RETURN
    6 DEDX=DIVX(J)
      RETURN
    7 J=J+1
      IF(J-NA)1,1,10
   10 J=NA
      GO TO 5
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
. FUNCTION ELSI(EE,N)

      FUNCTION ELSI(EE,N)
      IF(N)1,1,10
   10 GO TO(1,2,3,4,5),N
C     CARTER ARTIFICIAL
    1 ELSI=7.0995E-1*EXPF(-0.575*EE-0.055*EE**2)
      RETURN
C     ARTIFICIAL(N=2)MAR
    2 IF(EE-2.0)21,21,22
   21 ELSI=7.1E-1*EXPF(-1.4*EE)/.2599127E09
      RETURN
   22 ELSI=1.5E+0*EXPF(-0.96*EE)/.2599127E09
      RETURN
C     VAN ALLEN(N=3)
    3 ELSI=(1.7E+0*EXPF(-5.75*EE)+8.0E-3*EXPF(-1.8*EE))/.3000961
      RETURN
    4 ELSI=4.080*EXPF(-EE/0.58)
      RETURN
    5 CONTINUE
      RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE WEGUES(A,B,N,ANSER,RELERR)

      SUBROUTINE WEGUES(A,B,N,ANSER,RELERR)
C     INTEGRATION ROUTINE FOR A FUNCTION
C
C     COMPUTE INTERVAL H, WITH INITIAL GUESS R, UPPER LIMIT B, AND
C     LOWER LIMIT A
C
      L=1
      R=2.
      H=(B-A)/R
C
C
      AREA=FUNCT(B,N)
      PSUM=AREA/2.
      SAREA=FUNCT(A,N)
      PSUM=PSUM+SAREA/2.
      NN=R
      MM=NN-1
      W=A
      DO 2 I=1,MM
      W=W+H
      PAREA=FUNCT(W,N)
    2 PSUM=PSUM+PAREA
      TSUM=PSUM*H
      IF(L-1)1500,3,4
 1500 CALL EXIT
    1 H=(B-A)/R
      W=A+H
      DO 8 I=1,MM
      PAREA=FUNCT(W,N)
      W=W+(2.*H)
    8 PSUM=PSUM+PAREA
      TSUM=PSUM*H
      IF(L-1)1500,3,4
    3 FINT1=TSUM
      MP=MM+1
      L=L+1
      R=R*2.
      GO TO 1
    4 FINT2=TSUM
      MM=MM+MP
      IF(ABSF((FINT1-FINT2)/FINT1)-RELERR)5,5,6
    6 R=R*2.
      FINT1=FINT2
      GO TO 1
    5 ANSER = FINT2
      RETURN
      END(1,0,0,1,0,0,0,0,0,1,0,0,0,0,0)
```

SAMPLE INPUT DATA

```
*      DATA
    1    43
0.1        10.0       1.0
0.01       24.6       0.02       14.3       0.03       10.4       0.04       8.38
0.05       7.11       0.06       6.23       0.07       5.59       0.08       5.11
0.09       4.72       0.10       4.41       0.15       3.46       0.20       2.98
0.25       2.70       0.30       2.51       0.35       2.38       0.40       2.28
0.45       2.21       0.50       2.15       0.55       2.10       0.60       2.07
0.65       2.04       0.70       2.01       0.75       1.99       0.80       1.98
0.85       1.96       0.90       1.95       0.95       1.94       1.0        1.94
1.20       1.92       1.40       1.91       1.60       1.91       1.80       1.91
2.0        1.91       2.2        1.91       2.4        1.92       2.6        1.92
2.8        1.93       3.0        1.93       4.0        1.96       5.0        1.98
6.0        2.00       8.0        2.03       10.0       2.06
 NASA SAMPLE PROBLEM
     2    -1     1     1     1  0  0     1.0     .5    13.0  APLLO GUT4
     2    0.5
     1    5.0         0.5
     2    1.0         0.5
     2    0.5
     1    2.0         0.5
     2    2.0         0.5
```

SAMPLE PROBLEM

PROBLEM NUMBER 1

NASA SAMPLE PROBLEM

ELECTRON FLUX = 1.000/CM**2/SEC, FRACTION OF INCIDENT FLUX ENTERING SHIELD = 0.500
SPECTRUM NUMBER = 1, ATOMIC NUMBER OF SHIELD MATERIAL = 13.000

DOSE (RADS/SEC)	THICKNESS (GM/CM**2)	SOLID ANGLE
0.16640E-13	6.00000	0.50000
0.17226E-11	4.00000	0.50000

TOTAL DOSE = 0.8696123E-12RADS PER SEC

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3. Mar, B. W., "The Calculation of Bremsstrahlung Penetrating a Space Vehicle," The Boeing Company, Document D2-90411, May 1963.

4. Carter, R. E., Reines, F., Wagner, J. J., and Wyman, M. E., "Free Antineutrino Absorption Cross Section. II. Expected Cross Section from Measurements of Fission Fragment Electron Spectrums," Phy. Rev. 113, 280, 1959.